Air Pollution and Respiratory Health among Children with Asthmatic or Cough Symptoms

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During the winter of 1994, the association between daily changes in air pollution and in the respiratory health of children 7 to 12 yr of age were studied in Kuopio, Finland. Seventy-four children with asthmatic symptoms and 95 children with cough only, living either in urban or suburban areas, were followed for 3 mo. During the study period, the mean daily concentration of particulate air pollution (PM10) was 18 $\mu g/m^3$ in the urban area and 13 $\mu g/m^3$ in the suburban area. Lagged concentrations of PM10, black smoke, and NO_2 were significantly associated with declines in morning peak expiratory flow (PEF) among asthmatic children. The regression coefficient ($\times$ 10) for a 2-d lag of PM10 was -0.911 (SE, 0.386) in the urban and -1.05 (0.596), in the suburban area. Among children with cough only, PM10, black smoke, and NO_2 were not significantly associated with PEF. In the urban area, there was a significant association between SO_2 and morning and evening PEF and incidence of upper respiratory symptoms among children who cough only. No other associations between air pollution and evening PEF or respiratory symptoms were observed. This study suggests that particulate air pollution is associated with respiratory health, especially among children with asthmatic symptoms. Timonen KL, Pekkanen J. Air pollution and respiratory health among children with asthmatic or cough symptoms. AM J RESPIR CRIT CARE MED 1997;156:546–552.

Recently, several studies have reported associations between air pollution and respiratory health in asthmatic children (1, 2). Health effects have included lung function decrements, increased asthma attacks, increased use of bronchodilators, increased respiratory symptoms, and increased hospital admissions (3–7).

The studies on this association among nonasthmatic children are not very consistent. Koenig and coworkers (8) found a negative association between pulmonary function and fine particulate matter among asthmatic children, but not among nonasthmatic children. Similarly, Roemer and coworkers (5) reported that particulate matter with a diameter of less than 10 μm (PM10) and sulphur dioxide (SO_2) were more consistently associated with decrements in peak expiratory flow (PEF) among asthmatic children than among children who had suffered from chronic cough but not from asthmatic attacks. In addition, Neas and coworkers (9) found that children with no chronic respiratory symptoms appeared to be less susceptible to the effects of air pollutants on PEF than were symptomatic children. Hoek and coworkers (10) reported that there was a negative association between particulate air pollution and lung function among children with or without chronic respiratory symptoms. This was true also among children who had suffered from chronic cough during the previous 12 mo. However, this subgroup of children with cough included also children with asthmatic symptoms. Pope and Dockery (4) have also reported a negative association between PEF and PM10 pollution among both symptomatic and asymptomatic children.

Compared with children with dry cough as their only respiratory symptom, asthmatic children have been reported to have lower lung function values, expressed as maximal midexpiratory flow, and a larger prevalence of atopy and bronchial hyperresponsiveness (11–13). Therefore, we hypothesized that adverse effects of short-term changes in air pollution on respiratory health would be stronger among asthmatic children than among children with cough as their only respiratory symptom.

METHODS

Study Area

The present study was conducted in Kuopio, a town of 80,000 inhabitants in eastern Finland. The center of Kuopio constituted the urban area, and a suburb of Kuopio, Petonen, which is located 10 km south of the center, was chosen as the suburban area. The main sources of air pollution in the center of Kuopio are traffic, a municipal peat-fired district heating power plant (295 MW), and a corrugation cardboard

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The data were collected within the framework of the PEACE study. The PEACE study is a study on Effects of Short-term Variations in Urban Air Pollution on Respiratory Health of Children with Chronic Respiratory Symptoms. PEACE stands for "Pollution Effects on Asthmatic Children in Europe". The study was funded by the EU ENVIRONMENT Programme Contract EV5V-CT92-0220 (seven centers) and two additional EU PECO contracts to allow participation of five centers in Central and Eastern Europe. The Finnish, Norwegian and two Swedish centers were funded by grants from the respective Governments. The study was coordinated by the Department of Epidemiology and Public Health, University of Wageningen, Wageningen, The Netherlands.

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mill. In the suburban area, there are no heavy traffic or industrial air pollution sources, and the buildings are less than 10 yr old.

Finland has a four-season climate. During the cold period in winter (January to March), low temperatures and low wind speeds may cause inversion episodes with elevated air pollution levels. During the winter months from December to April, the ground is usually covered with snow in Kuopio.

Study Population

In September 1993, a screening questionnaire on respiratory symptoms used in the PEACE study was distributed through schools to 2,995 primary school children in the urban and suburban areas (11, 14). The questionnaire was completed by parents and then returned to the school. The questionnaire was completed and returned by 2,564 children (86%), and 2,544 of the children were 7 to 12 yr of age. A total of 229 children with chronic respiratory symptoms were asked to participate in this study. These children were from four schools in the center of town (urban panel) and from two schools in the suburb of Petonen (suburban panel). One hundred ninety-seven of these children, 100 in the urban and 97 in the suburban area, agreed to, and were characterized with, skin prick tests and spirometry. The detailed results of the screening and characterization phase have recently been published (11).

Chronic respiratory symptoms included wheeze in the previous 12 mo, attacks of shortness of breath with wheezing in the previous 12 mo, dry cough during the night apart from colds in the previous 12 mo, and ever doctor-diagnosed asthma. The children who had suffered from wheezing, attacks of shortness of breath with wheezing, or had doctor-diagnosed asthma are referred to as "asthmatic children." The children who had dry cough as their only respiratory symptom are referred as "children with cough only." In the beginning of the study, there were 45 asthmatic and 55 children with cough only in the urban panel, and 40 asthmatic and 57 children with cough only in the suburban panel. Because only children who had valid diary data on more than 60% of the possible days are included in the present analyses (15), the final sample size is 39 asthmatic and 46 children with cough only in the urban panel, and 35 asthmatic and 49 children with cough only in the suburban panel. The characteristics of the children are presented in Table 1.

PEF Measurements and Symptom Diaries

During winter 1994, the children were followed for 3 mo. They measured peak expiratory flow (PEF) rate three times every morning and every evening in the standing position with a mini-Wright Peak Flow Meter (Airmed; Clement Clarke International Ltd, Essex, UK) before taking any respiratory medication. All three PEF readings were noted in a diary, and the largest of these three readings was used for the analyses (14).

The children also kept a daily diary on respiratory symptoms with help from their parents. The following symptoms were reported: cough, phlegm, runny or stuffed nose, awakened with breathing problems, shortness of breath, wheeze, attack(s) of shortness of breath with wheeze, fever, eye irritation, and sore throat (14).

The study protocol was approved by the Ethical Committee of the University of Kuopio and of the Kuopio University Hospital. A written consent was obtained from the parents of the children.

Air Pollution and Weather Data

The concentrations of PM10, black smoke (BS), and nitrogen oxides (NO_x) were measured at fixed sites in urban and suburban areas. Sulphur dioxide (SO_2) was measured only in the urban site. In addition, carbon monoxide (CO) was measured at both sites, and ozone (O_3) in the suburban site. Both sites were at least 50 m from the closest busy road and had a sampling height of about 4 m (14, 16).

Twenty-four-hour concentrations of PM10 were collected with single-stage Harvard impactors (Air Diagnostics and Engineering, Inc., Naples, ME) (17). BS was sampled according to the OECD (Organization for Economic Cooperation and Development) protocol (18). The reflectances of the BS filters were measured at the University of Wageningen, The Netherlands. Gaseous pollutants were measured with continuously recording monitors (16). The concentrations of the gaseous pollutants are given as mass concentrations at 0° C. Twenty-six percent of the hourly NO_x data were missing in the suburban area and were modeled. The R^2 of the model was 0.58, mainly because of

TABLE 1

CHARACTERISTICS OF THE PANELS OF CHILDREN WITH EITHER ASTHMATIC OR COUGH SYMPTOMS

	Urban Area		Suburban Area	
	Asthmatic*	Cough Alone	Asthmatic	Cough Alone
n_{start} †	45	55	40	57
$n_{analyses}$ ‡	39	46	35	49
Average number participating on any given study day	33	38	30	41
Girls, %	46	57	31	43
Mean (SD) age, yrs	10.7 (1.9)	10.4 (1.5)	10.2 (1.5)	10.4 (1.7)
Mean (SD) height, cm	141 (11)	138 (11)	135 (10)	138 (10)
Mean (SD) weight, kg	38.5 (10.7)	34.6 (9.8)	33.3 (7.8)	34.1 (9.4)
% with doctor-diagnosed asthma	54	—	63	—
Prevalence of atopy, %§	77	52	74	57
Smoking inside the home, %‖	3	15	0	2
Mean (SD) morning PEF, L/min	339 (63)	345 (60)	336 (63)	340 (58)
Mean (SD) evening PEF, L/min	343 (63)	349 (61)	340 (62)	343 (56)
Prevalence of lower respiratory symptoms on any given day during the study period, mean, %	22	14	19	11
Use of bronchodilators on any given day during the study period, mean %	13	0	30	0
Reported using asthma medication during study period, %¶	24	2	33	6

* Asthmatic symptoms: doctor-diagnosed asthma, or wheezing during the previous 12 mo or attacks of shortness of breath with wheezing.

† Number of children who started the follow-up.

‡ Number of children with valid PEF and diary data on more than 60% of the days and thus included in the analyses.

§ Atopy defined as having at least one positive reaction in skin prick tests.

‖ Smoking by anyone, reported in a questionnaire.

¶ Asthma medication: bronchodilators, inhaled corticosteroids, sodium cromoglycate, nedocromil sodium.

O_3, but the model included also CO, wind speed and direction, time trend, and temperature.

Daily temperature and humidity data were obtained from the weather station network of the City of Kuopio. Daily pollen counts collected with Burkard volumetric pollen trap were obtained from the Finnish Aerobiology Group (19). The sampler is located at the University of Kuopio, which is near the center of the town.

Study Period

The ambient air measurements were started on January 24, 1994, and ended on April 30, 1994. The first week of this period was taken as a test period. PEF measurements were started January 31 to February 3, 1994. To accommodate learning effects on PEF measurements, the study period for analyses started on February 8. At least the first 2 d of the diary of each child were excluded even if a child started filling in the diary later than February 6. The follow-up was extended until the end of April. However, the first pollen episode began on April 6, and therefore, time series analyses are restricted to the period February 8 to April 5, 1994.

Statistical Methods

Data were analyzed by using the statistical package SAS/STAT® (SAS Institute Inc., Cary, NC) (20). The analyses were conducted separately for each panel using the day as the unit of analyses (3, 15). The daily mean PEF deviation (ΔPEF) was calculated for morning and evening PEF. First, a mean morning and evening PEF for each child was calculated. Second, this mean value was subtracted from the daily value of morning or evening PEF of the child. These daily deviations (ΔPEF) were then averaged to obtain the daily mean ΔPEF of morning and evening PEF in the panel. Associations of daily mean ΔPEF with air pollutants were analyzed with a linear first-order autoregressive model by using the SAS procedure MODEL. First, a basic model that included other determinants of ΔPEF, i.e., time trend (a linear, squared, and cubic term for the day of the study), weekend, minimum temperature (lag 0), and relative humidity (lag 0) was established. In this model, residuals were found to be normally distributed. To this basic model, the concentrations of air pollutants of the current 24-h (lag 0), the previous day (lag 1), 2 d before (lag 2), and the average of the four previous days (4-day average) were added one at a time. In order to take into account the different sample sizes per day, each day was weighted by the number of children reporting a PEF value for that day. As sensitivity analyses, analyses were repeated using adjustments used in the PEACE project (15), including a dummy variable for a 2-wk period when residuals were found to be negative, but the results remained essentially unchanged. In addition, analyses were conducted for children with doctor-diagnosed asthma. Two-pollutant models were also studied.

As further sensitivity analyses, the association between morning PEF and PM10 was studied using analysis of covariance, where the child day is the unit of analyses (proc GLM). In addition to the confounders of the basic model above, these models included a dummy variable for each child, but no adjustment for autocorrelation. In a third set of models, the possible interaction between symptom status and PM 10 was tested in analysis of covariance adjusting for the basic confounders, and weight, height, sex, age, and atopic status of the child.

In symptom analyses, five binary variables indicating daily symptoms were analyzed. Lower respiratory symptom was defined as present when the child reported having on a given day, at least one of the following symptoms (slight, moderate, or severe): shortness of breath, wheeze, or attacks of shortness of breath. Upper respiratory symptom was defined being present when the child reported having (slight, moderate, or severe) sore throat or runny or stuffed nose. Cough, phlegm, and eye irritation symptom recordings were also dichotomized to 0 (= no symptom) and 1 (= slight, moderate, or severe symptom) before the analyses. Incident cases were defined as a positive report of a symptom by a child who had not reported that symptom on the previous day (14).

Weighted logistic regression models were used to analyze symptom prevalences (proc MODEL) and symptoms incidences (proc NLIN) (21). The models were adjusted for time trend (including a linear, square, and cubic term of the day of the study), weather variables (including a linear and squared term of the minimum temperature of the current day and the relative humidity of the current day), weekends, and first-order autocorrelation. The concentrations of air pollutants of the current 24-h (lag 0), the previous day (lag 1), 2 d before (lag 2), the average of the four previous days (4-day average) were added to this model one at a time. The number of children with valid symptom data on a given day was used as weight.

RESULTS

Temperature and Air Pollutant Concentrations

The average daily concentrations of air pollutants were higher in the urban area than in the suburban area (Table 2). All pollutants correlated negatively with temperature (Table 3). The correlations in daily air pollution concentrations were high between the urban and suburban areas. Between the areas, the correlation coefficient for PM10 was 0.73, for BS it was 0.83, and for NO_2 it was 0.66. During January 1994, the monthly average temperature in Kuopio was −9.4° C. In February, March, and April the corresponding temperatures were −16.6° C, −5.0° C, and 3.5° C, respectively. The coldest daily average temperature (−29.5° C) was measured on February 12, and the lowest minimum temperature was observed (−31° C) a day before.

PEF and Air Pollution

A negative association between morning ΔPEF and PM10 was observed among children with asthmatic symptoms in both areas (Table 4). Statistically significant associations were observed at lagged PM10 concentrations. Among asthmatic children, the plots of the morning ΔPEF versus quartiles of 4-d average and lab 2 of PM10 concentrations, adjusted for time

TABLE 2

AVERAGE DAILY LEVELS OF THE AIR POLLUTANTS AND MINIMUM TEMPERATURE IN THE URBAN AND SUBURBAN AREAS DURING THE STUDY PERIOD, FEBRUARY 8 THROUGH APRIL 5, 1994

	Days (*n*)	Mean	25% Percentile	50% Percentile	75% Percentile	Maximum
Minimum temperature, °C	57	−8.5	−14	−7	−1	3
Urban area						
PM10, μg/m^3	57	18	10	14	23	60
Black smoke, μg/m^3	57	13	6	10	16	57
NO_2, μg/m^3	55	28	17	25	36	78
SO_2, μg/m^3	54	6.0	2.6	3.6	7.1	32
Suburban area						
PM10, μg/m^3	57	13	8	11	18	37
Black smoke, μg/m^3	57	8	2	6	11	47
NO_2, μg/m^3	55	14	7	12	18	51

TABLE 3

CORRELATIONS* BETWEEN AVERAGE DAILY LEVELS OF THE AIR POLLUTANTS DURING THE STUDY PERIOD, FEBRUARY 8 THROUGH APRIL 5, 1994

	PM10	Black Smoke	NO_2	SO_2†	Minimum Temperature
Urban area					
PM10, μg/m³	1.0	0.65	0.58	0.21	−0.41
Black smoke, μg/m³		1.0	0.92	0.20	−0.45
NO_2, μg/m³			1.0	0.22	−0.51
SO_2, μg/m³				1.0	−0.25
Suburban area					
PM10, μg/m³	1.0	0.79	0.40		−0.28
Black smoke, μg/m³		1.0	0.78		−0.57
NO_2, μg/m³			1.0		−0.73

* All correlations above 0.18 significant at level 0.05.
† SO_2 available only in the urban area.

trend and weather variables, showed no evidence for a threshold in the association (Figure 1). Lag 2 of BS and NO_2 concentrations were also negatively associated with morning ΔPEF among asthmatic children. Among children with cough only, air pollutants were not significantly associated with morning ΔPEF, except SO_2, which had a negative association with morning and evening ΔPEF in the urban panel.

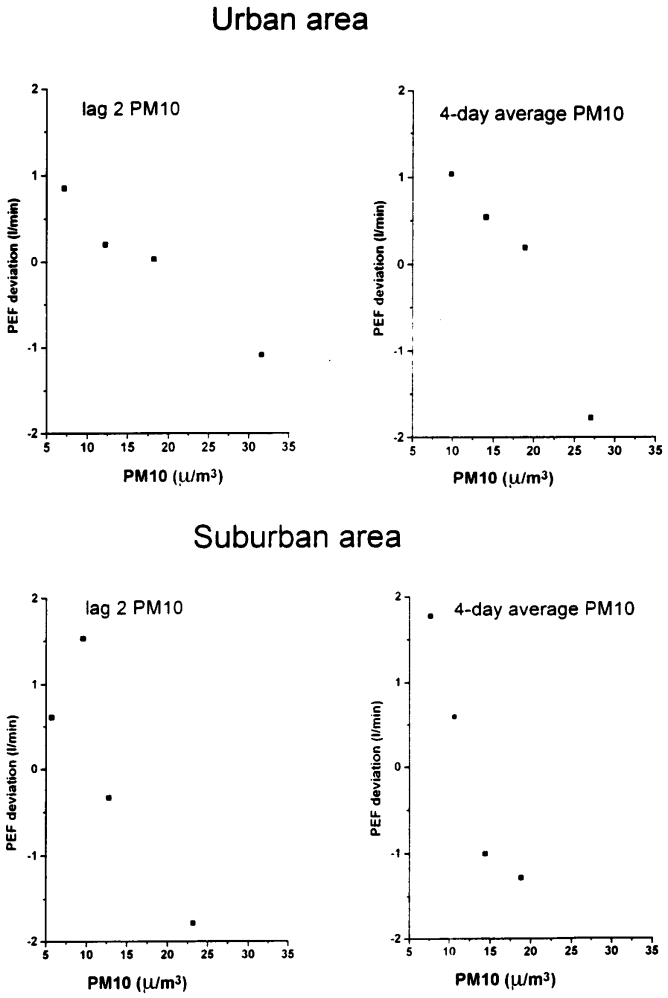

Figure 1. Plots of adjusted morning PEF deviation by quartiles of 4-d average and of lag 2 of PM10 (μg/m³) among asthmatic children in the urban area and in the suburban area. Adjustments are for time trend, minimum temperature, relative humidity, and weekends.

TABLE 4

ADJUSTED* ASSOCIATIONS OF 24-H LEVELS OF AIR POLLUTANTS AND MORNING PEF DEVIATIONS AMONG CHILDREN WITH ASTHMATIC OR COUGH SYMPTOMS

			Urban Area		Suburban Area	
			Asthmatic	Cough Alone	Asthmatic	Cough Alone
PM10	Lag 0	Coeff.†	−0.586	0.463	0.001	0.024
		SE	0.449	0.353	0.563	0.427
	Lag 1	Coeff.	−0.568	0.414	−1.11‡	−0.222
		SE	0.414	0.306	0.573	0.414
	Lag 2	Coeff.	−0.911§	0.345	−1.05‡	−0.487
		SE	0.386	0.295	0.596	0.424
	4-day mean	Coeff.	−1.81‖	0.751	−3.29§	−0.959
		SE	0.643	0.462	1.35	0.730
Black Smoke	Lag 0	Coeff.	0.063	0.421	0.417	−0.205
		SE	0.463	0.422	0.512	0.435
	Lag 1	Coeff.	0.098	0.350	−0.295	−0.408
		SE	0.419	0.367	0.473	0.372
	Lag 2	Coeff.	−0.868§	−0.016	−0.780‡	−0.354
		SE	0.413	0.383	0.461	0.361
	4-day mean	Coeff.	−0.712	0.619	−1.74	−0.951
		SE	0.991	0.706	1.30	0.679
NO_2	Lag 0	Coeff.	0.149	0.323	0.965	−0.321
		SE	0.362	0.306	0.637	0.483
	Lag 1	Coeff.	−0.073	0.210	−0.155	−0.159
		SE	0.328	0.272	0.577	0.434
	Lag 2	Coeff.	−0.548‡	−0.105	−0.949‡	0.132
		SE	0.312	0.266	0.533	0.421
	4-day mean	Coeff.	−0.355	0.407	−0.113	−0.162
		SE	0.599	0.408	1.81	0.899
SO_2	Lag 0	Coeff.	0.198	−0.229	—	—
		SE	0.804	0.608		
	Lag 1	Coeff.	0.382	−1.38§	—	—
		SE	0.789	0.564		
	Lag 2	Coeff.	0.648	−0.683	—	—
		SE	0.715	0.523		
	4-day mean	Coeff.	1.39	−1.28§	—	—
		SE	1.14	0.633		

* Adjusted for time trend, minimum temperature, relative humdity, weekends, and autocorrelation. One pollutant in the model at a time.
† Regression coefficients (Coeff.) and standard errors (SE) × 10.
‡ $p < 0.1$.
§ $p < 0.05$.
‖ $p < 0.01$.

After adjusting only for autocorrelation, the introduction of the possible confounders to the models had only a little effect on the estimates of lag 2 of PM10 in both areas and on the estimate of 4-d average of PM10 in the urban area. In contrast, the introduction of the confounders doubled the estimate of 4-d average of PM10 in the suburban area.

Among children with doctor-diagnosed asthma (n = 21 in the urban panel, and n = 22 in the suburban panel), the effect of PM10 on morning PEF was similar to or even slightly larger than those presented in Table 4 for asthmatic children. In the urban panel, the regression coefficient (SE) for the 2-d lag of PM10 (× 10) was −1.14 (0.589) and for the 4-d average of PM10 it was −2.61 (1.13). The respective regression coefficients in the suburban panel were −1.40 (0.769) and −4.87 (1.61).

When introducing both PM10 and NO_2 into the model at the same time, the regression coefficients for PM10 remained essentially unchanged among asthmatic children in both pan-

els. For lag 2, the regression coefficients for both PM10 and NO_2 lost statistical significance, however. In the urban area, the regression coefficients (SE) for the 4-d average concentration ($\times$ 10) were −2.20 (0.772) for PM10 and 0.577 (0.631) for NO_2. In the suburban area, the coefficients were −3.47 (1.46) and 0.022 (0.754), respectively.

In the sensitivity analyses using analysis of covariance, estimated regression coefficients for PM10 were similar to those in Table 4. In the urban panel, the regression coefficient (SE) for lag 2 of PM10 ($\times$ 10) was −0.591 (0.303) and for the 4-d average of PM10 it was −1.41 (0.532). The respective regression coefficients were −1.70 (0.770) and −3.87 (1.38) in the suburban panel. Among children with cough only, the regression coefficient of the 4-d average of PM10 ($\times$ 10) was 0.639 (0.658) in the urban panel and −0.533 (0.655) in the suburban panel.

Although the estimated effects of air pollution on morning PEF among children with asthmatic symptoms and among children with cough only were different (Table 4), the interaction terms between symptoms status and PM10 pollution variables did not reach statistical significance either in the urban ($p = 0.537$ for lag 2 of PM10, $p = 0.687$ for the 4-d average of PM10) or in the suburban area ($p = 0.156$ for lag 2 of PM10, $p = 0.194$ for the 4-d average of PM10). However, when the two areas were analyzed together, adjusting also for area and including an interaction term between temperature and area, the interaction terms between symptom status and lag 2 of PM10 ($p = 0.0002$) and the 4-d average of PM10 ($p = 0.0001$) were highly statistically significant.

No consistent associations were observed between air pollutants and evening ΔPEF (Table 5). In the urban panel, SO_2 had a negative, statistically significant association with evening ΔPEF among children with cough only, whereas the association was positive and approached significance among the asthmatic children.

TABLE 5

ADJUSTED* ASSOCIATIONS OF 24-H LEVELS OF AIR POLLUTANTS AND EVENING PEF DEVIATIONS AMONG CHILDREN WITH ASTHMATIC OR COUGH SYMPTOMS

			Urban Area		Suburban Area	
			Asthmatic	Cough Alone	Asthmatic	Cough Alone
PM10	Lag 0	Coeff.	−0.222	0.033	−0.333	−0.571
		SE	0.418	0.418	0.673	0.389
	Lag 1	Coeff.	0.133	0.160	0.064	−0.396
		SE	0.379	0.371	0.705	0.391
	Lag 2	Coeff.	−0.226	0.076	0.076	−0.642
		SE	0.372	0.359	0.689	0.390
	4-day mean	Coeff.	−0.146	0.238	−0.837	−1.07
		SE	0.732	0.610	1.71	0.719
Black Smoke	Lag 0	Coeff.	−0.028	−0.077	−0.515	−0.340
		SE	0.398	0.442	0.622	0.399
	Lag 1	Coeff.	−0.294	−0.205	0.488	−0.322
		SE	0.367	0.404	0.574	0.343
	Lag 2	Coeff.	0.028	0.204	−0.178	−0.516
		SE	0.380	0.416	0.566	0.331
	4-day mean	Coeff.	0.296	−0.630	−0.778	−0.850
		SE	0.937	0.877	1.53	0.678
NO_2	Lag 0	Coeff.	−0.063	0.285	−0.695	−0.172
		SE	0.325	0.334	0.759	0.455
	Lag 1	Coeff.	−0.188	−0.019	0.418	−0.176
		SE	0.291	0.290	0.672	0.396
	Lag 2	Coeff.	0.087	0.096	−0.479	−0.476
		SE	0.287	0.294	0.713	0.393
	4-day mean	Coeff.	0.042	0.347	−2.86	−0.585
		SE	0.575	0.502	1.90	0.881
SO_2	Lag 0	Coeff.	1.28‡	−1.84§	—	—
		SE	0.711	0.673		
	Lag 1	Coeff.	0.575	−0.144	—	—
		SE	0.727	0.711		
	Lag 2	Coeff.	0.819	−0.291	—	—
		SE	0.642	0.613		
	4-day mean	Coeff.	1.34	−0.878	—	—
		SE	1.05	0.868		

* Adjusted for time trend, minimum temperature, relative humidity, weekends, and autocorrelation. One pollutant in the model at a time.
† Regression coefficients (Coeff.) and standard errors (SE) $\times$ 10.
‡ $p < 0.1$.
§ $p < 0.01$.

Respiratory Symptoms and Air Pollution

There was no clear and consistent trend in the association between air pollution and symptom prevalence in any of the four panels. Symptom incidences were also not consistently associated with air pollution, except among children with cough only in the urban area. Among them, increase in SO_2 levels was associated with an increase in the incidence of upper respiratory symptoms. The odds ratio for a 10 $\mu g/m^3$ increase in SO_2 concentration was 1.46 (95% confidence interval, 1.07 to 2.00) for lag 1 of SO_2, 1.46 (1.14 to 1.87) for lag 2, and 1.55 (1.08 to 2.24) for the 4-d average of SO_2. When excluding the three highest days of SO_2 from the analyses, the odds ratio of lag 2 of SO_2 concentration remained the same, but it lost its statistical significance. The odds ratio for lag 1 of SO_2 concentration was reduced to 1.13 and for the 4-d average to 1.12, and both were nonsignificant. No significant associations were found between SO_2 and morning or evening PEF, or respiratory symptoms among the children with cough only in the suburban panel when using the SO_2 concentrations measured in the urban area as the exposure variable.

DISCUSSION

In the present study, particulate air pollution was associated with decrements in morning PEF. This effect was observed at relatively low PM10 concentrations. The study was conducted during winter time, when most particles originate from combustion processes, and the temperature stayed mostly below 0° C. The association was observed among children with asthmatic symptoms, whereas no significant association was found among children with dry chronic cough as their only respiratory symptom. This difference between children with asthmatic symptoms and those with cough only was also statistically significant. The results were not sensitive to model specifications or to the method of analysis.

The strongest effects were observed at lagged air pollution concentrations, and there was also a suggestion for a cumulative effect. Lag 2 and the 4-d average of PM10, and lag 2 of BS and NO_2 were all associated with declines in morning PEF. When PM10 and NO_2 were simultaneously adjusted for, the most consistent association was found for PM10. Among asthmatic children, morning PEF decreased by 0.27% in the urban area and by 0.31% in the suburban area for a 10 $\mu g/m^3$ increase in daily mean PM10 concentration (lag 2). The respective declines were 0.26 and 0.23% for a 10 $\mu g/m^3$ increase in daily mean BS concentration (lag 2). In a recent combined analysis (1), there was a 0.08% decrease in PEF associated with 10 $\mu g/m^3$ increase in PM10 daily mean concentration among school children. In the study of Neas and coworkers (9), a 0.19% decrease in PEF per 10 $\mu g/m^3$ of daily mean PM10 (lag 0) was reported among symptomatic children.

The results supported the previous observations that asthmatic children are more sensitive to effects of air pollution

than are nonasthmatic children or children with only cough symptoms (4, 5, 8–10). However, some previous studies have found an effect of particulate pollution on health also among nonasthmatic children (4, 10). In these studies, however, the average 24-h concentrations of PM10 were higher than in the present study. This suggests that also nonasthmatic children may suffer from adverse effects of particulate air pollution when the ambient air concentrations are higher.

There are a few possible reasons why asthmatic children may be more sensitive to effects of air pollution. Asthmatics may have preexisting airway narrowing, which greatly enhances bronchial hyperresponsiveness and thus leads to an exaggerated response of the airways to exogenous stimuli (22). This is because, first, a given absolute change in airway diameter will produce a larger increase in airflow resistance if initial diameter is reduced. Second, increases in bronchial tone may potentiate the stimulation of irritant receptors and the initiation of reflex bronchoconstriction. Peripheral lung resistance may be considerably increased in asthmatic subjects even if their total resistance or FEV_1 is within normal limits. Third, aerosol deposition is likely to be more central in the presence of airway narrowing, and this may increase stimulation of afferent receptors, which are most common in central airway (22, 23). In addition, increases in airway wall thickness, which have negligible effects on airway resistance under baseline conditions, can greatly amplify the increase in resistance produced by a normal contraction of airway smooth muscle. Airway wall thickening in asthma only has a small effect on relaxed luminal diameter, but it greatly enhances the rise in resistance in response to a given degree of smooth muscle shortening (22, 24).

Adverse effects of air pollution were observed on morning PEF but not on evening PEF. Airway narrowing in asthma is frequently at its worst in the early morning hours (22), and the difference in PEF between asthmatic and normal children has been reported to be largest in the morning (25). Morning PEF is not interfered with by daily activities or possible medication used during the day, and it may therefore be a more sensitive indicator of airway narrowing than is evening PEF.

Our panels of asthmatic children included both children with ever doctor-diagnosed asthma and children with recent symptoms of wheezing, which makes the panel somewhat heterogenous. However, the effect estimates of PM10 remained unchanged, when the analyses were repeated among only those children with doctor-diagnosed asthma. This is probably due to overlapping reporting of recent asthmatic symptoms. In the screening phase of this study, 70% of the children with ever doctor-diagnosed asthma had suffered from wheezing during the previous 12 mo, and 76% of the children who had wheezed during the previous 12 mo had also suffered from attacks of shortness of breath with wheezing (11).

Children with cough only may form a more heterogenous group than asthmatic children. Questions on chronic cough have been reported to be less reproducible than questions on asthmatic symptoms (26). However, 55% of the children with cough only were atopic and, in the screening questionnaire, they were reported to have allergy more frequently than asymptomatic children (11). Moreover, among this same population of symptomatic and asymptomatic children, there was a good agreement between questionnaire-based results and the results based on clinical evaluation (27). This confirms that the question on chronic cough was able to select children who were potentially more susceptible to the effects of air pollution.

No consistent association was found between air pollution and respiratory symptoms. The only exception was the association between SO_2 and incidence of upper respiratory symptoms among children with cough only in the urban area. This was supported by the association between SO_2 (lag 0) and evening PEF. Among asthmatic children there was no negative association between SO_2 concentrations and PEF in the urban area. The concentration of SO_2 was not measured in the suburban area. SO_2 levels in the study area were extremely low. However, potentially different subgroups may be sensitive to different air pollutants. The lack of association between other air pollutants and respiratory symptoms may be due to the insensitivity of the diary method at these low air pollution levels (10).

Present results show that effects of air pollution are larger among asthmatic than among other children. Also, studies on mortality have shown that air pollution mostly affects susceptible populations such as the elderly and those with preexisting disease (28, 29). This suggests that the effects of air pollution should be studied among susceptible populations. Firstly, because the effect of air pollution are usually small and can be seen only among these populations, but importantly also because air quality guidelines should also protect the most sensitive subjects from the adverse effects of air pollution (30).

In conclusion, this study has suggested that particulate air pollution is associated with respiratory health, especially among children who suffer from asthmatic symptoms, but not among children with cough as their only respiratory symptom.

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